Mortars for Masonry and Rendering

Choice and Application

by Kenneth Sandin

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1 Introduction

Problem

Masonry and rendering[1] tend to be carried out routinely, without any special thought. A common idea is that one should use as “strong” a material as possible, and as a result mortars are often rich in cement. Not only is this unnecessarily expensive, it also has technical disadvantages. Structures become very rigid and often sustain extensive cracking. Because of great internal tensions, the plaster might flake or shear off the background material.

It is also common that a layer of plaster is applied too thickly. Not only does this take too much mortar, but it increases the risk of flaking and cracking.

Cement mortar is considerably more difficult to work than lime mortar. To compensate more cement and water is often added. The resulting mortar is much too strong and has high shrinkage, greatly increasing the risks of cracking and flaking. Increasing cement also increases impermeability, which means a damp wall dries more slowly.

There is no question that there are great advantages in using cement in mortars; for example, it is easier to control the hardening process. At the same time there are serious disadvantages to a cement mortar, and unfortunately the advantages are often overstated. Generally large amounts of cement are not needed for strength, and in some cases adding cement may produce more disadvantages than advantages.

Gypsum plaster is common in some countries, particularly for interior walls. The material is not treated in this report.

Method

This report was written as a desk study. It is based on the author’s 20 years of research on mortar in Sweden and his participation in many consultancies and development projects. This basic material has been reworked and adapted to conditions in developing countries through studies of the literature, interviews and field studies in these countries.

Organization of the Report

The report consists of two parts, Chapters 1–3 and Chapters 4–6. Part 1 gives a brief description of the issue and recommendations. Part 2 is three independent appendices describing test methods, giving recipes for standard mortars, and estimating the amounts of mortar needed for typical masonry and rendering jobs.

2 General Considerations

Masonry and rendering are among the oldest techniques in building, and there are numerous examples from ancient Egypt, Assyria mad Rome.

The original function of mortar was probably to seal permeable walls and provide protection from rain and wind. That is obviously still a function today, but as building techniques developed, the demands on mortars increased greatly. For example, durability and an aesthetically pleasing appearance are required today. In some cases a mortar must also resist mechanical stress, chemically aggressive environments and extremely heavy moisture loads.

The choice of material and its application must always be appropriate for the specific situation, with its unique requirements. These requirements should neither be exaggerated nor undervalued. A very important factor is the conditions under which the work is done. Often requirements are expressed as qualities of the finished masonry or rendering, but these properties are closely related to the conditions during building and application.

For the finished masonry or rendering to have the intended properties, it is crucial that the fresh mortar has the right qualities that allow the work to be well executed. Different weather conditions during work, different absorbencies of the masonry units[2] and the hardening conditions have a determining effect on the final quality. A good rule is that only half of the final quality can be attributed to the standard properties of the mortar, while the other half depends on how the work was done. Using mortar that has ideal properties according to laboratory tests can be a disaster if the fresh mortar is so difficult to work with that the job is not well done!

To illustrate this situation one can compare rendering and masonry.

For rendering the strength of the mortar is usually unimportant, but good adhesion is a basic requirement. Adhesiveness depends entirely on the qualities of the fresh mortar. Cement mortar is rough and difficult to spread, and the risk of poor adhesion is obvious. High internal tension during curing leads to great stress in the contact area. Even if cement mortar has good qualities, it does not work well in rendering.

With masonry the requirement is sometimes for great strength, while in other cases quick setting is essential to be able to continue building, for example when constructing walls with non-absorbing stone. If one uses pure lime mortar in such cases, it could take several days for the joints to set before construction could continue.

In choosing the material and how it should be applied, consideration should also be given to local conditions, traditions, the workers and tools available. It is always important to think about the whole chain of steps that lead to the final result. Defining the final product is just a small part of the whole.

1 Rendering is to spread mortar or another mix on an external wall. Compare with plastering, which usually refers to finishing a ceiling or internal wall. The words have different meanings in US and UK English, and are often used interchangeably. The material used in rendering is often called plaster.

2 Bricks, blocks or stones.

Mortars for Masonry and Rendering

Mortar is very similar in structure to concrete, both in their fresh and final states. One adds a certain amount of fine material to concrete for watertightness, while the fine material is added to mortar to improve texture and workability.

For concrete one can in principle decide the strength required and calculate the proportion of cement directly. That is not possible for mortar, because the final product is so dependent on the conditions during application. For example, the strength and durability depend on the absorbency of the background material at the moment the mortar is applied.

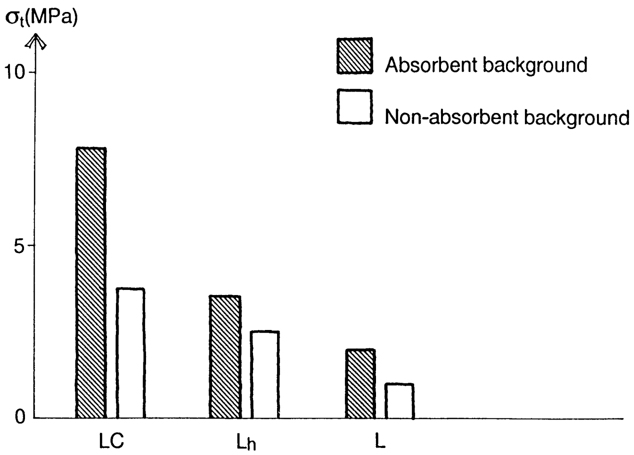

Fig. 1 Strength of Mortars Applied to Different Materials. L = lime, C = cement, L_h = hydraulic lime.

If the same mortar is applied to an absorbent and a non-absorbent background material, the strength of the mortar on the non-absorbent material is about half that on the absorbent material. Typical absorbent materials are dry masonry units made of burnt clay or concrete; while typical non-absorbent materials are non-porous natural stone and wet masonry units. The same is true for other properties, such as frost resistance. The reason the background material is so important is that mortar hardens on a non-absorbent surface with a significant excess of water, and thus develops a more porous mortar. Most of the properties described in the literature refer to mortars used on absorbent backgrounds. When choosing a mortar in practice, consideration must be given to the effect of the background.

Components

Mortars consist of binder, aggregate and mixing water. There might be different additives or admixtures for special purposes, such as:

- pigments for a specific colour
- hydrophobic materials to resist rain
- air-entraining agents to improve frost resistance
- agents to improve consistency and workability.

The choice of type and amount of binder and aggregate is always a compromise between the qualities of the fresh and the hardened mortar.

The role of the binder is to glue together the separate particles of aggregate. The two types of binder are non-hydraulic and hydraulic.

Non-hydraulic binders cure only in air, while hydraulic binders cure both in air and in water. The non-hydraulic binder is *slaked lime (L)*. The oldest hydraulic binder is *hydraulic lime (L_h)*, produced from, for example, limestone containing clay. During the 1800s *cement (C)* was developed, and today this is the main hydraulic binder. During the 1900s the binder for mortars was modified by mixing cement and slaked lime *(lime-cement LC)*. Pure cement and finely ground limestone are also mixed to masonry mortar *(masonry cement M)*.

An ordinary lime mortar, or lime putty, hardens in two stages. In the first stage it dries, producing calcium hydroxide crystals which strengthens the mortar. In the second stage, when the moisture content drops sufficiently, the real curing, carbonation, begins. The calcium hydroxide reacts with the carbon dioxide in the air to form calcium carbonate. This process is necessary for good mortar quality and occurs slowly from the outside inwards. Poor climatic conditions (too dry, too wet or too cold) can seriously interfere with carbonation. The optimal relative humidity (RH) is 60–80%.

For hydraulic binders, curing is a chemical process that begins as soon as water is added. Curing occurs uniformly through the mortar and requires water.

The normal ***aggregate*** in mortars for masonry and rendering is natural sand. The aggregate is the largest component and forms the structure of the mortar. The sand should not contain humus[3], and should not include more than 10% by volume of clay or silt, since they give higher shrinkage.

The maximum particle size of the sand depends on the use of the mortar. For masonry the maximum particle size should be about 1/3 the width of the joint. For rendering, the particle size depends on the finish desired, normally no more than 1/3 to 1/2 of the thickness of the layer.

The grain-size distribution of the sand should be continuous. The principle for grain-size distribution is that all the spaces between the larger particles are filled by smaller particles. The grain-size distribution should lie within the range shown in the figure. The amount of fine material (< 0.25 mm) has great importance for the work-

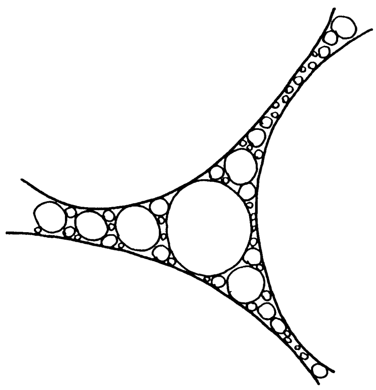

Fig. 2 Aggregate Framework. All the spaces between the larger particles are filled by smaller particles.

3 Organic material produced by the decay of plants.

ability of the mortar. If one uses little fine material (near the lower curve), the mortar is difficult to work.

If the aggregate is crushed stone, the mortar is generally difficult to work, but workability can be improved by increasing the amount of binder and filler (aggregate with a grain-size < 0.075 mm). In such situations, tests are recommended to see if there are any negative effects.

Most stone materials are suitable as aggregate, although soapstone (steatite), mica and slate should be avoided.

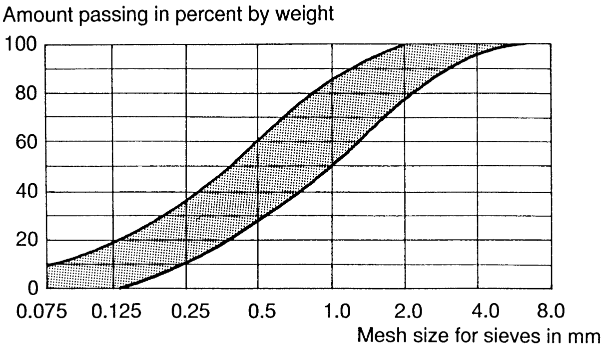

Fig. 3 The Grain-size Distribution should lie within the range shown.

Mixing water has two functions in mortar; it makes the mortar workable and it allows the chemical reactions. Water used in the preparation of mortar should be clean, and may not contain salt or organic contamination.

Admixtures are often the same as used in concrete. Admixtures should normally be used in very small quantities. An excess could have disastrous results. There is always a risk that an admixture that improves one property will at the same time worsen another. Considering the risks with admixtures, they should not be mixed in on the site! With industrial production under controlled conditions, some admixtures could be appropriate, such as an air entraining agent to produce a smoother mortar, or a hydrophobic compound to reduce water absorption. Any use of admixtures must be based on laboratory tests with exactly the components to be used in the mortar.

Types of Mortar

Mortars for masonry and rendering can be roughly divided into five strength classes as shown in the table in Chapter 5.

The description of a mortar always includes the type of binder and the amount of binder and aggregate. The amounts of binder and aggregate should always be expressed as parts by weight; for example LC 50/50/650 means 50 kg lime, 50 kg cement and 650 kg sand. As an alternative the components can be expressed in volumes; that is LC 2:1:12 which means 2 parts lime by volume, 1 part cement by volume, and 12 parts sand by volume. These mortars are identical. Note that the equivalence shown only applies for "normal" densities, as follows.

Lime	650 kg/m^3
Cement	1300 kg/m^3
Sand	1300 kg/m^3

The theoretical proportions are based on volume, but batching on the site is done by weight[4], so if the aggregate has another density, it is necessary to recalculate the recipe. Convert the proportion of sand by volume to weight, using the actual density. For example, if the sand has a density of 500 kg/m^3, the amount of sand should be reduced to 500/1300 of the given weight.

The most important property of **fresh mortar** is workability. Generally this increases with a greater proportion of lime in the binder or a greater total amount of binding agent, but going to extremes has negative effects, such as shrinkage during curing.

There is always some shrinkage during hardening, which can cause cracking. Usually shrinkage increases with the amount of binder, which means that one should not use more binder than necessary. Shrinkage also increases with greater lime content, but this is normally not a problem since it occurs when the mortar is still plastic. Cement-rich mortars normally shrink less, but the shrinkage occurs at a later stage and causes greater tension in the material. *The risk for cracking and other negative effects is thus greater with a cement-rich mortar.*

The strength, rigidity, frost resistance and density of **hardened mortar** increases with higher cement content.

Mixing Mortar

The **components** should be measured by weight. Batching by volume can give the same result if done very carefully, but there are many sources of error. Do not measure by shovel: errors of 50% are not uncommon when a shovel is used to portion the ingredients. A firm container with the exact volume must be used if batching by volume. The moisture content of the aggregate is significant with volume portioning, since the volume increases greatly with moisture. A 5% increase by weight in the aggregate can mean a 40% increase in volume, if it contains a lot of fine grained material.

Manual mixing should be avoided, since there is always great risk for a badly mixed mortar. If one is forced to mix by hand, the binder and dry sand should be mixed together first. Then the water is added carefully to avoid washing away the binder. The mixing must be done very carefully, both when the ingredients are dry and after water is added.

Mechanical mixing should always be used if possible. The dry materials are first mixed together, and then water is added. The simplest kind of machine is a free fall mixer. It always rotates slowly and is based on the principle that the mortar is lifted up and falls down of its own weight. If the mixture does not fall down, but travels around the drum, no real mixing occurs! Under good conditions the mixing time should be at least 10 minutes.

In a paddle mixer the container is stationary while the paddle arms rotate. In a contraflow mixer the container and the paddle arms rotate in opposite directions. These machines are much more efficient than a free fall mixer and give a homogeneous mixture. The mixing time should be about 10 minutes.

4 Weighing the components is likely to give less error than batching by volume. See below (mixing mortar)

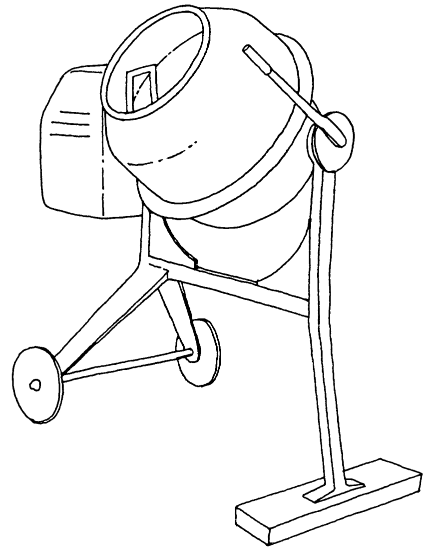

Fig. 4 Free Fall Mixer.

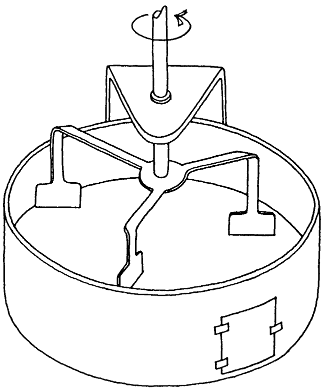

Fig. 5 Paddle Mixer.

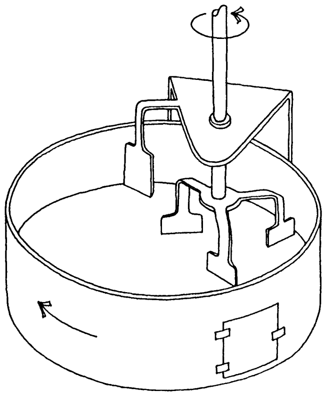

Fig. 6 Contraflow Mixer.

Mixing water should always be added carefully, and the amount adjusted to the purpose of the mortar and the requirements of the mason. Mortars containing cement or other hydraulic binders must be used within 3–4 hours. When mixing is complete, no further water should be added to reduce stiffness! Non-hydraulic lime mortars can be used indefinitely, if they are kept damp and do not dry out.

The binder should always be stored dry on the work site. Even the sand should be kept as dry as possible. Prepared mortar should be kept in the shade.

Masonry

A masonry wall must meet several requirements.
The most important are:

- adequate strength
- good impermeability
- good durability.

These requirements imply certain specific demands for the

- masonry unit (bricks, blocks, stones)
- mortar
- interaction between bricks and mortar.

The **masonry units** must have a certain strength and resistance to degradation. Most of them fulfil these requirements; others, such as sun dried clay blocks (adobe), do not normally do so. One must take extra measures when using these, such as mechanically anchoring a protective rendering into the wall.

The **mortar** should in principle meet the same standards as the bricks.

The **interaction between masonry units and mortar** is crucial for the final qualities of the wall. The most important factor is the adhesion between the masonry unit and mortar. Poor adhesion always results in defective strength and impermeability. Masonry units have different strengths and absorbencies. This implies that different kinds of units place different demands on mortars and work techniques. The masonry unit and the mortar must always be appropriate for each other, both to allow the masonry work to be done with sufficient care and so that the wall functions for a long time.

Choice of Mortar

When choosing a mortar, strength is not the only consideration. The interaction between the masonry units and the mortar is at least as important. For good interaction, the mortar must be smooth and easily worked.

The mortar should have about the same strength as the masonry units. *If the mortar is much stronger, there is always a risk for cracking*.

The absorbency of the masonry units is important for laying them, for adhesion and for the setting of the mortar. If they have very low absorbency, and the main component of the mortar is lime, it will take a long time for the joint to set. This could mean that the units lie and “float” in the fresh mortar, leading to large deformations in the wall. On the other hand if the units are very absorbent, a cement-rich mortar can lose so much mixing water that curing stops. Much too great absorbency could even cause the mortar to set before the units can be put in their final position.

When choosing a mortar, one should:

1 Decide a suitable strength

2 Adjust the mortar to the absorbency of the masonry units.

The basic principle in the choice of the binder is:

- choose a lime-rich binder for weak, highly absorptive units;
- choose a cement-rich binder for strong, low-absorption units.

Never use more cement than required for strength.
Note also that *a stronger mortar does not always give a stronger wall*. The result could be the opposite.

The table gives examples of suitable mortars for different masonry units. Note that the table is only a guide. The characteristics of a certain type of unit could vary significantly. The given mortar proportions apply when the aggregate is natural sand with a good grain size distribution. Other types of sand and grain size distributions often give a less easily workable mortar. This could be compensated with additional lime, but avoid using too much lime since other negative effects could arise. If the recipe is changed, practical tests are recommended.

Tab. 1 Examples of Mortars for Units of Different Absorbencies and Strengths

	High absorption Low strength	*Low absorption High strength*
Solid and hollow concrete blocks, natural stone	LC 35/65/550 (LC 1:1:8)	C 100/450 (C 1:4)
Bricks and hollow blocks of burnt clay, calcium silicate units	LC 50/50/650 (LC 2:1:12)	LC 35/65/650 (LC 1:1:10)
Aerated lightweight concrete Cement stabilized soil blocks	LC 60/40/700 (LC 3:1:16)	LC 50/50/650 (LC 2:1:12)
Sun dried clay units (adobe)	L 100/800 (L 1:4)	LC 60/40/700 (LC 3:1:16)

L = lime, C = cement. For example, LC 35/65/550 means the proportion of lime/cement/sand by weight. LC 1:1:8 means the proportion of lime:cement:sand by volume.

Application

The most important requirements for masonry are that the joints are completely filled with mortar, and that no units are adjusted after the mortar has set. If these requirements are not met, the wall will have less strength and tightness.

The joints should be as thin as possible allowing for any unevenness in the units; 10–15 mm is an optimal thickness.

Masonry units with high absorbency can remove the mixing water so quickly that there is not enough time to place the units precisely before the mortar sets. This invariably leads to a permeable wall. The only way to prevent this is to dip the units in water before placement.

The adhesion between masonry unit and mortar can be easily checked by breaking off a unit some minutes after it is laid. If the entire contact surface is covered with mortar, the adhesion is satisfactory.

Units are laid by spreading sufficient mortar where the new unit will be placed. Just before the unit is placed, whether it is solid or perforated, a dab of mortar is put on the end face that will lie against existing units. Then the unit is placed on the spread mortar, and pressed diagonally down and in towards the existing unit to fill the joint completely. Any gaps are filled immediately. A bricklayer’s hammer is used to adjust the unit into its final position. The unit should not be disturbed after this.

If the units are laid in this way, the joints will be completely filled to the front of the wall. If the facade will not be rendered, the joint should be finished as soon as the mortar has set somewhat. Tooling is most efficiently done with a rounded tool, a little wider than the joint. This compresses the joint and the mortar is pressed against the masonry units. Finally the surface is cleaned with a dry brush.

Joints with different shapes obviously require different tools. What is important is that the joint is thoroughly compressed.

If the tooling is done afterwards (which should be avoided), the joints should be scraped 15 mm deep and cleaned with a dry brush. The joint should be first wetted, then filled completely with mortar and finished as described above.

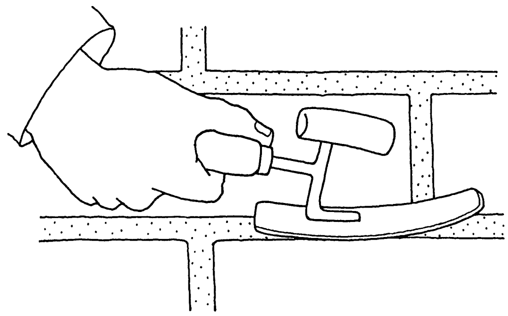

Fig. 7 Tool for Tooling.

Masonry work in progress should be protected from heavy rain, to avoid leaching of the mortar. When the work is complete, the wall should be protected from rapid drying in direct sunlight.

If the masonry units are likely to shrink significantly after manufacture, such as concrete blocks, they should be allowed to cure and dry before use. For some units this could take months.

The heading (vertical) joints cannot always be filled, for natural reasons, when laying hollow bricks or hollow blocks. For this reason, these walls must always be rendered to make them tight. Even when using solid or perforated bricks in walls that will be rendered, there is less requirement for the vertical joints on a single line to be completely filled. However it is always better to fill all joints while laying the unit.

Rendering

A rendering has several functions, such as:

- to protect the building from external climatic and mechanical stresses,
- to create an aesthetically pleasing appearance,
- to create a smooth surface for a final finish.

Often one wants to achieve more than one of these aims at the same time, which places other demands on the choice of the mortar and the rendering system. Consideration must also be given to the existing background material; a weak and a strong background have completely different requirements. The mortar must in other words be adapted to the background and certain other conditions. If this is not done, there is no prospect of fulfilling the general functions listed above. The mortar must also be adjusted to the bricklayer’s needs, such as that it is easy to work with. A mortar with poor workability always carries a great risk that the job cannot be well done, which can result in the plaster dropping off. Good adhesion is always necessary for the rendering to function, and this is established at the moment of application. The mortar must make complete contact with the background. If this is not achieved, there is no prospect for satisfactory adhesion. The requirement for workability is at least as important as other demands. The final choice

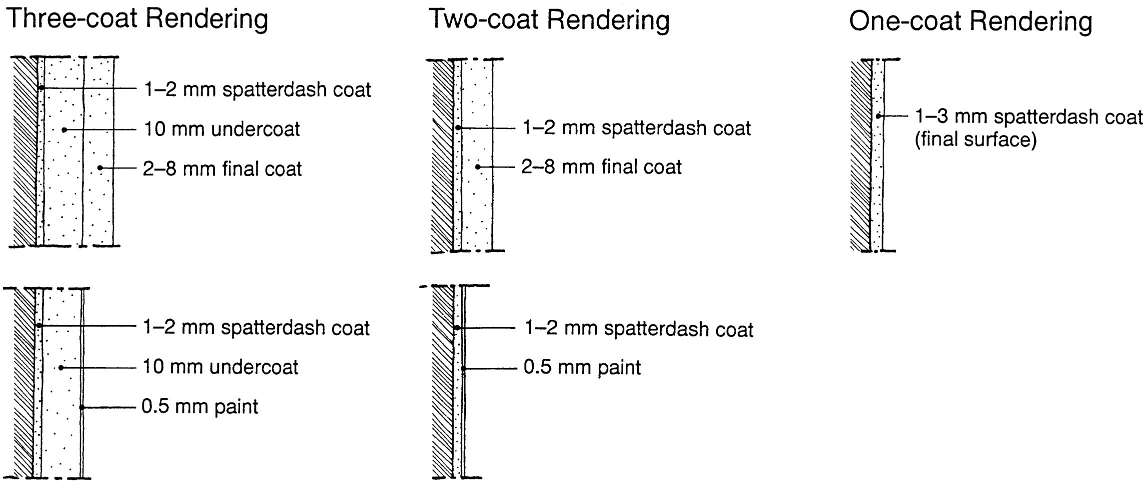

Fig. 8 Types of Rendering Systems.

of mortar and the rendering system is always a compromise between different demands.

Rendering System

This is determined by the background material, anticipated stress and aesthetics. The number of coats in the rendering varies. The simplest is just one coat, and normally the maximum is three. A basic principle in building up the rendering is that the strength of each layer is less as one moves outwards.

The thickness of the rendering is determined by, among other things, the evenness of the background and the surface desired. If the background is relatively uneven, such as ordinary brickwork, and the surface is to be smooth, it is necessary to have a total thickness of 10–15 mm.

The thickest rendering consists of three coats: spatterdash coat, undercoat and final coat.

The main function of the **spatterdash** coat is to control and even out the absorbency of the background. Adhesion is established at the moment the render is applied, and for good adhesion the mortar must be in complete contact with the background. If the background has extremely high absorption, there is a risk that “normal” render will not wet it sufficiently, with a risk for poor adhesion. A spatterdash coat with a special composition that thoroughly wets the background will reduce absorbency enough that the undercoat in turn will wet the spatterdash coat.

If the background has little or no absorbency, it is difficult in practice to apply a thick rendering. The plaster slides off by its own weight. In this case the spatterdash coat can increase absorbency, which makes the succeeding steps easier.

The absorbency of the background can vary greatly on the same facade, for example between masonry units and mortar. Using a single coat on such a facade means that the characteristics of the finish will vary and, perhaps, later show a rectangular pattern. A spatterdash coat will largely eliminate these effects.

The spatterdash coat should be 1–2 mm thick and unbroken.

The undercoat primarily fills unevenness in the background and provides the desired flatness to the surface. It is also the background for the final coat, and provides an even suction for it. The undercoat is normally 8–12 mm thick.

The final coat is the visible layer of the finished rendering. It might, for example, be a paint or a coloured plaster.

If the pattern of the wall is to be seen through the coating, the traditional thick, three-coat rendering cannot be used. The thickness of the rendering should in this case be at most 4–5 mm. For this thickness one could, for example, chose to use two coats: spatterdash and final coat. For an even thinner cover, one could use just a spatterdash coat and paint. The simplest rendering is just one coat, such as a coloured render.

Choice of Mortar for Rendering

The higher the cement content, the higher the mechanical stress on the background during the time, and after, the mortar sets. *The basic principle in choosing mortar is therefore to choose a binder with the lowest cement content possible*. This is especially important for weak backgrounds. The thickness of the rendering is also very important in this context, since increasing the thickness always increases tension on the background. The thicker the rendering, the more lime-rich the binder should be.

Tab. 2

Examples of Rendering Mortars

Background *Coat*	*Weak* *eg cement stabilized soil block*	*Medium* *eg brick*	*Strong* *eg concrete*
Spatterdash coat	LC 35/65/400 LL_h 35/65/500	LC 10/90/350 LL_h 10/90/500	LC 10/90/350
Undercoat	LC 50/50/950 LL_h 40/60/650 L 100/800	LC 50/50/650 L_h 100/750	LC 35/65/550
Final coat	LC 50/50/950 LL_h 40/60/650 L 100/800	LC 50/50/650 L_h 100/750	LC 35/65/550 LC 50/50/650

Note: Do not combine cement based mortar with pure lime mortar; eg it is completely wrong to cover a spatterdash coat of hydraulic lime with an undercoat of LC mortar.

It is not possible to give standard mixtures for all purposes. The recipes below are, however, useful in most cases. By using the guidelines above, one can modify the mortar to suit almost any possible situation.

Application

The method of application is perhaps the most important factor in rendering. This applies to the whole chain from preparation to follow-up.

Clean the surface that will be rendered. This is essential for good adhesion. Salt deposits, loose particles and dirt must be removed. This is done primarily by brushing with a stiff brush. Some cases might require thorough washing.

Fill all holes with the same mortar to be used for rendering. Larger gaps are repaired with the same material the wall is made from. Walls with high absorbency should be wetted before repairing. All holes should be filled so that the thickness of the rendering coat will not exceed 15 mm. All repairs should set for at least 3–4 days before rendering is applied. During this period the repairs should be treated as new rendering.

Reinforcement is necessary in some situations to prevent or reduce cracking. Types of surfaces that should be reinforced are

- transitions between different materials
- large and deep repairs
- large areas on very weak backgrounds

Reinforcement should be done with welded, galvanized wire net, with a wire diameter of about 1 mm and a mesh size of about 20 mm. (Avoid weak netting, such as chicken netting, since it stretches.) The netting must be fastened with galvanized nails or special clips. The reinforcement should extend at least 200 mm on each side of the different materials or repairs. If welded net is not available, reinforcement can be done with 1 mm steel wire. The wires are laid 20 mm apart in a square grid pattern.

Wet all highly absorbent backgrounds before applying the spatterdash coat, so that the background does not immediately absorb the mixing water. Wetting is important both for good adhesion and for the curing of the spatterdash coat. Rapid drying increases the risk for low strength and cracking. If the weather is dry and hot, it might be necessary to repeat the wetting several times before applying the spatterdash coat. Wetting should not be excessive, however, so that all absorbency disappears.

The spatterdash coat is a fluid mortar, the consistency of thin porridge. This is applied manually or with a spray and spread to a thickness of 1–2 mm. When it is hot and dry, the spatterdash coat should be wetted to prevent rapid drying. It should cure for 1–3 days before the undercoat is applied. Very long curing (months) should be avoided.

The undercoat is applied 1–3 days after the spatterdash coat. If the weather is hot and dry, the spatterdash coat should be wetted carefully before the undercoat is applied. The undercoat is applied manually or with a spray, to a maximum thickness of 15 mm. When the mortar has firmed a little (after the background has absorbed some of the mixing water), the surface is evened with a straightedge drawn in sawing movements from bottom to top. On very absorbent backgrounds, this must be done after a few minutes. On background with low absorbency, it might be necessary to wait several hours before smoothing can be done. The surface can still be somewhat rough at this stage, since it provides a good base for the next coat. However, if the undercoat is to be a smooth final layer, the surface must be finished with a hand float. Before this can be done, the mortar must be allowed to set longer, to avoid accumulating too much fine material on the surface, which gives great risks for cracking. For the same reason the treatment should not be excessive. In practice it is difficult to treat the surface at exactly the right moment. If it is too dry, it can be wetted by carefully sprinkling on water with a brush.

In dry and hot weather, the rendered surface should be wetted carefully. Running water should not be used.

The final coat should be applied in accordance with the manufacturer’s recommendations. The time between the application of the undercoat and the final coat is not critical. To avoid colour irregularities, the under coat should have a completely even absorbency (moisture content). The surface should be dry for some final coats and damp for others. Some should be wetted after, and others should not.

Wetting of the finished rendering should be done in warm, dry weather. Mortars containing cement must be kept damp for at least three days. Pure lime mortar should not be wetted too much, since that will inhibit curing.

Other considerations are:

- Place scaffolding sufficiently far from the wall to avoid blocking the work.
- Protect the facade from direct sunlight and heavy wetting (eg driving rain) before, during, and for at least one week after rendering.
- Lead away water that collects on the roof so it does not run down the facade.
- Cut away any mortar that sticks to wood.
- The entire facade should be treated at one time to avoid variations in colour and structure. If this is not possible, select natural break points.

Moisture Conditions

Moisture in walls often has serious negative consequences, such as:

– salt deposits, salt spalling or salt impregnation[5]
– direct leakage into the building
– impaired adhesion of the surfacing
– corrosion of reinforcement
– accelerated deterioration
– colour changes
– fungus growth

5 These salts are hygroscopic and absorb water, which causes the wall to remain damp even when the weather has been dry for a long time.

– damp in adjacent building components, such as wood
– impaired thermal insulation
– frost damage.

Many of these problems can be prevented or reduced through very simple measures. Often these are obvious, once the source of moisture is identified and the transport mechanisms are understood.

Moisture Sources and Transport Mechanisms

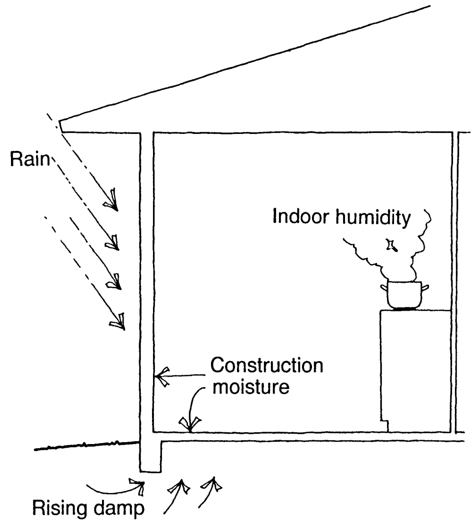

Fig. 9 Sources of moisture.

The main sources of moisture affecting masonry are:

- rain
- humidity
- construction moisture
- rising damp.

Rain striking a facade is called ***driving rain***. With strong wind the proportion of driving rain can be significantly greater than rain falling vertically. Masonry normally absorbs all driving rain at the beginning. (Surface treatment can however have a great influence.) If the driving rain is very heavy or continues a long time, the rate of absorption can be lower than the load. A film of water forms on the surface. If there are cracks in the surface, the water can run directly into the wall. There is normally no flow of water through masonry units or mortar.

As soon as the rain stops, the wall begins to dry. Water is transferred by capillary action to the surface of the facade, where it quickly evaporates. All surface treatments interfere to some extent with drying out. Even a pure lime plaster greatly reduces the speed of drying out. The rendered wall dries only 5–10% as fast as a wall without rendering.

If a damp wall is exposed to direct sunlight, the moisture in the wall is transported inwards. If the wall covering on the inside is not permeable, moisture can collect between it and the wall. This can also occur behind paintings and wall hangings. The risk increases with lower indoor temperatures, such as when air conditioning is used. Increased humidity always means an increased risk for mould.

Humidity indoors is normally higher than outdoors. When indoor air is cooled, the relative humidity increases, with a consequent risk for condensation on room surfaces. If the room has a permeable surface treatment, the moisture is absorbed by a masonry wall and does not cause any great problem. However, if the room is painted with an impermeable organic paint, the paint itself can have a high moisture content, with a risk of mould and rot.

Construction moisture is the surplus moisture immediately after the building is completed. There can be very large amounts of water involved with masonry and rendering.

Rising damp is the movement of water up the wall from the ground by capillary action. This water often includes salts that, over time, accumulate in the walls. This can lead to salt deposits and even salt spalling on the walls. Non-permeable surface coatings always increase problems with rising damp.

Reducing the Moisture Load

The basic means to minimize the negative effects of ***driving rain*** is to make the walls tight and free of cracks. This is achieved by choosing a mortar that is compatible with the masonry units, filling joints completely, and ensuring good adhesion between the masonry units and the mortar or render.

Other important ways to reduce the loads from driving rain through building design are:

- generous roof overhangs
- adequate copings on wall headings
- weepholes or other water drainage devices where there is a risk of water entering
- devices to keep water off the facade, such as window sills and roof gutters.

Construction moisture should dry out as quickly as possible after the wall hardens. The best method to hasten drying out is high ventilation before applying the indoor surface finish.

Prevent ***rising damp*** from being sucked into the walls. The external base of the wall should be protected with a layer of asphalt or similar. There should be a moisture barrier between the bottom of the wall and the foundation. The ground should slope away from the building.

Surface Coatings

Different surface coatings can have completely different characteristics with completely different effects on the facade. Service life can vary from a few years to 40–50 years. Some coatings can affect the moisture content in the facade, while others have no significant effect on it.

The risks for damage or undesired effects later are almost always determined by the choice of the surface coating. With this in mind, it is very important to be aware of the most basic characteristics of different surface coatings and the consequences of choosing one or the other.

Types of Surface Coatings

The surface coating is defined as the final layer in a facade treatment. The composition of the surface coating and the thickness can vary greatly. The binder might be organic or inorganic. The thickness can vary from molecules to several centimetres. Described below are ***normal paints*** according to their binder. (A paint can easily be converted to a render by increasing the aggregate size according to a previous section.)

The most common inorganic binders are *lime, lime-cement*, *cement* and *silicate*. A common characteristic of these paints is that they have little effect on moisture in the facade. They also do not produce a completely even colour, but often show tones, creating a more living surface.

Lime paints consist of lime, water, pigments and perhaps filler as aggregate. Lime paints have relatively poor durability and are mainly used on lime rendering. The durability varies greatly depending on the exposure to driving rain, normally between 2 and 20 years. An advantage of lime paint or wash is that it does not have any mechanical effect on the background and is easy to maintain by repainting.

Lime-cement paints consist of lime, cement, water, pigment and filler. They are significantly more durable than lime paints, and the paint can be used on both lime and lime-cement renderings. The mechanical effect on the background is about the same as with lime paint, or a little greater. A disadvantage of lime-cement paint is the risk for white deposits on dark colours. Lime-cement paint is easy to maintain by repainting.

Cement paints consist of cement, water, pigment and filler. Durability is good. The paint is mainly used on cement and lime-cement renderings. The mechanical effect on the background is greater than lime or lime-cement paint, and too much repainting can cause flaking.

Silicate paints consist of water glass (sodium silicate), pigment, admixtures and filler. The binder reacts chemically with the base, giving greater adhesion and mechanical effect on the background than the other inorganic paints. Silicate paint have very good durability and can be used on all mineral backgrounds with a fair strength.

Organic (plastic) paints have a wide range of binders and characteristics. Common for the group is that they have a great effect on the moisture balance in the facade. This can be both positive and negative. They also move extensively with changes in temperature and moisture, which create great mechanical stresses on the background. Organic final coats therefore require relatively high strength backgrounds. If an organic paint is used correctly, durability is good. There are, however, risks for rapid deterioration, if the paint is applied to a poor background.

Choice of Final Coat

The choice does not depend only on the background. Other requirements and preferences might also be important. Some significant factors to consider are:

The strength of the ***background*** determines the strength of the final coat. If the strength is low, the choice is limited to lime paint or lime-cement paint. If the background is strong, any paint may be chosen.

The choice of ***colours*** might rule out paints containing cement. There is a great risk of unattractive white patches forming on dark colours.

The ***uniformity of colour*** varies greatly between different types of paint. Inorganic paint almost always shows some shifts in tone, while an organic paint gives a very even colour.

Maintenance has great economic importance. A low building in the countryside can easily be repainted, while a multi-storey building in the city centre requires greater effort and inputs to repaint. In this latter case there is good reason to choose a more expensive alternative, if the maintenance intervals are longer.

The effect on moisture might be crucial. If there is risk of, for example, rising damp or large amounts of construction moisture, organic paints should not be used. In areas with heavy driving rain, inorganic paints allow the wall to become wet. The moisture can even be transported to the inside. To reduce the moisture content in this case, choose water repellent organic paints (or inorganic paints with water repellent admixtures).

Application

Painting should always be done according to the manufacturer's instructions for the paint. The general rules are as follows, even for lime, lime-cement and cement paints mixed on the site:

- The background should be cleaned of all dirt and loose particles.
- Before applying lime, lime-cement or cement paint, wet a highly absorbent background.
- Do not paint in intense sunlight, rain or if there is risk for frost.
- Arrange for water drainage from the roof before starting to paint.
- Newly painted facades should be protected from intense, direct sunlight and rain.
- Paints containing lime or cement should be kept damp for three days after painting. Water should not however run on the facade.
- The entire facade should be painted at one time to avoid colour variations. If this is not possible, choose natural breaks.
- Paint should be stirred frequently to avoid separation in the container.

Maintenance

All facades require maintenance. There are no maintenance-free facades. The requirements for maintenance can, on the other hand, differ greatly among different facades. The principles for maintenance are based on two simple questions: **when** and **how** should it be done. The determining factor should always be what is most economical in the long term.

There can be many criteria for maintenance. Two of the most important are in general:

- Aesthetic effects, which reflect the level of ambition.
- Technical causes, which are important for the functioning of the building.

The first criteria can vary significantly between, for example, a midtown hotel and a simple rural building. The other criteria is common for all buildings and assumes continuous assessment and maintenance. Facades, roofs and drainage systems should, for example, be inspected annually. If any defects are discovered, they should be repaired immediately. A small defect is usually easy and cheap to fix. If the small defect is not repaired immediately, the result can be a rapid deterioration.

For different reasons it might not be possible to repair all defects at once. In such cases, it is important to assess the consequences on the different defects and set priorities. The technical criteria must always have precedence over the aesthetic. Roof gutters are often the most urgent. (It is a waste of money to repaint a damaged facade to make it look good, if the cause of the damage is left untouched.)

As far as how maintenance should be done, there is a simple answer. *Use in principle the same materials and method used originally, if they were not wrong from the beginning.*

This rule means that the need for maintenance can vary greatly between different buildings. If a cheap and easily worked material was used originally (such as lime paint on a rural building), one must reckon on more maintenance than if a more durable material (such as silicate paint on the midtown hotel) was used originally.

3 Recommendations

Mortars for Masonry and Rendering

Binder

Lime is the only non-hydraulic binder, and it takes a long time to cure. Curing is also unpredictable and is strongly dependent on the weather. An advantage of lime mortar is that the mixed material can be used indefinitely.

Hydraulic lime, lime-cement, cement, and masonry cement (cement mixed with fine limestone) are all hydraulic and cure relatively fast and reliably.

Hydraulic binders give a more predictable curing and are therefore preferable, which does not mean that a strong mortar is better. A disadvantage of hydraulic binders is that the prepared mortar has a limited period of use, about 3–4 hours.

Aggregate

The most common aggregate is natural sand. It must not contain humus, and there must nor be more than 10% clay and silt by volume. The grain size distribution should be continuous and preferably lie within the range shown in the figure on page 6 and 15. The largest grain size should be about 1/3 of the joint or render thickness. Most types of rock can be used, but not soapstone, mica or slate.

If crushed stone is used as aggregate, the filler content (aggregate with grain size < 0.075 mm) must be increased to achieve good workability.

Admixtures

No admixtures should be introduced at the site.

Water

The mixing water should be clean. Salt water may not be used.

Standard Mortars

The composition of the mortar must always be specified. No modifications are allowed on the site. Sometimes more binder is added to make a more workable mortar. This is not allowed! The mortars listed in Chapter 5 cover all normal uses.

Mixing

Mixing by machine is preferable. The dry components should be mixed together carefully before the water is added, and then the mortar should be mixed for about 10 minutes in a normal mixer.

Masonry

Choice of Masonry Mortar

Do not choose the strongest mortar available. Workability and compatibility with the masonry blocks are more important.

The strength of the mortar should be about the same as that of the masonry units. A too strong mortar can cause cracking in the wall.

Workability and compatibility with the masonry blocks normally increases with increased lime content in the binder.

Mortar for units with low absorbency should be relatively rich in cement. Blocks with high absorbency are better set with a lime-rich binder.

To choose a masonry mortar, first decide the appropriate strength. Then choose a mortar with as lime-rich a binder as possible, to get the best possible workability. For units with low absorbency, however, a more cement-rich mortar must be used.

Examples of suitable mortar for different uses are shown in the table on page 8.

Application

The joints should be 10–15 mm thick and very well filled. The joints should be filled in one step, and the units must not be shifted from their positions when the mortar has begun to set. If the units are very absorbent, the mortar might set so quickly that there is not enough time to adjust the blocks. In such cases the blocks must be dipped in water before setting.

The adhesion between units and mortar can be easily tested by breaking off a newly placed block. If the bed surface is covered with mortar, adhesion is satisfactory.

The joint is compressed and finished when the mortar has set somewhat. Avoid filling joints after the blocks are laid.

Any surplus mortar on the surface of the blocks should be removed before the mortar has cured.

During bricklaying the wall should be protected from direct sunlight and heavy driving rain.

Rendering

Rendering System and Choice of Render

There are normally 1–3 layers in a rendering. The strength of the layers should decrease moving away from the wall.

The base layer, the ***spatterdash coat***, should be 1–2 mm thick. The mortar should be fluid and be made of LC 10/90/350 or LL_h 10/90/500. On very weak backgrounds, use instead LC 35/65/400 or LL_h 35/65/500.

The next layer, the ***undercoat***, functions to level any unevenness and give the facade the desired flatness. It is usually 8–12 mm thick. For most facades, the following are suitable: LC 50/50/650 or L_h 100/750. On very weak backgrounds use LC 50/50/950 or LL_h 40/60/650.

The surface layer, the ***final coat***, can be a coloured mortar or a paint. The composition of the final coat should be the same in principle as the undercoat.

A complete rendering can even consist of only a spatterdash coat, a spatterdash coat and paint, or a spatterdash coat and an undercoat. A complete rendering may never consist only of the undercoat, or an undercoat and paint.

Application

A careful cleaning of the background is a basic condition for a good result.

Highly absorbent backgrounds should be wetted so that the mixing water is not absorbed before the render can be worked.

The spatterdash coat should be a very fluid mortar. It can be applied by brush or it can be laid on with a trowel and brushed immediately after. In dry weather, the spatterdash coat should be dampened to prevent it from drying out completely.

The undercoat is applied 1–3 days after the spatterdash coat. In dry weather, dampen after application.

An industrially produced final coat should be applied according the manufacturer’s instructions.

All lime and cement based renders should be kept damp for at least three days. They should not dry out completely during this period.

Finishes

Choice of Final Coat

The strength of the background is of crucial significance when choosing a final coat, which must never be stronger than the background. If the background is very weak, only lime paint can be used.

All final coats containing cement are unsuitable for dark colours.

The final coat can have a great influence on the moisture balance of the facade. In areas with a lot of driving rain, a water repellent final coat should be chosen, such as silicon resin paint.

Application

The background should always be carefully cleaned before the final coat is applied.

Absorbent backgrounds that will be treated with an inorganic final coat should be wetted. It is often necessary to wet the final coat after it is spread.

The application should not take place in direct sunlight or rain.

To avoid shifts in colour tones, the entire facade should be treated at one time.

Consult the manufacturer’s instructions.

Maintenance

All facades require some maintenance. It is especially important to repair as quickly as possible any defects that could have serious consequences, such as leaks. *A small effort at an early stage is always more economical than a major repair later when the damage has spread.*

For the facade itself, the basic rule is to use the same material and methods as the original. This obviously applies only if the facade was correctly treated from the beginning. If the material is to be changed, it must be changed on the entire facade.

4 Test Methods

The methods described here are generally very simple and do not require special equipment. These tests can help create the necessary conditions for a good, functional mortar. These tests are not intended to be used for the systematic classification of all aspects of mortars.

Aggregate

Humus and Silt Content
Humus can delay or even prevent the curing of the binder. High silt content weakens strength and give greater shrinkage. There should be no humus, and the silt content should be under 10% by volume.

Humus content is checked with a sodium hydroxide test. A clear glass container is filled half full of aggregate, and a 3% solution of sodium hydroxide is added up to 2/3 of the glass. The glass is shaken and allowed to stand for 24 hours. If the liquid over the aggregate is colourless or light yellow, the sand can safely be used. If the liquid is brown, it is likely that the sand contains so much humus that it cannot be used. The brown colour might be caused by iron contamination, which is not dangerous. In order to determine whether it is humus or iron, it is necessary to do chemical analyses or make test mixes.

Silt content is determined in the same glass container. After shaking the largest particle will sink first and lie on the bottom. The fine silt sinks more slowly and lies on top. The vertical thickness of the silt layer is measured and expressed as a percent of the total aggregate.

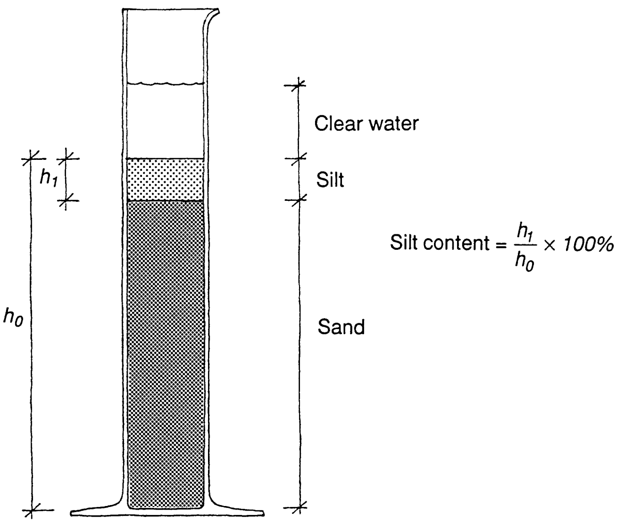

Fig. 10 Determination of Silt Content.

Grain-size Distribution
Grain-size distribution should lie within the curves in the grading diagram in Figure 11.

At least 500 g of aggregate is dried and weighed. The sample is poured into a sifter with sieves of mesh size 4.00, 2.00, 1.00, 0.50, 0.25, 0.125, 0.063 mm and a solid bottom. The device is shaken until no material passes to the next layer. The amount of material in each sieve is

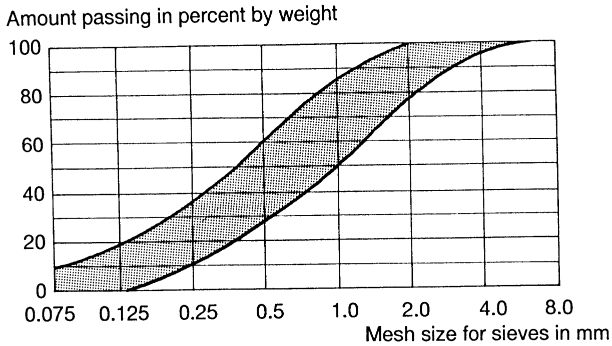

Fig. 11 Limit Curves for Aggregate.

weighed. The percentage of material that goes through each sieve is calculated. The amount that passes the 0.063 sieve is found on the solid bottom. Everything that goes through the 0.125 sieve is the sum of the material on the bottom and in the 0.063 sieve, and so forth. The combined weights of the material in each sieve should be added and checked against the original weight of the sample.

The results are expressed in a grading diagram.

Fresh Mortar

Separation of Mixing Water
When the prepared mortar stands undisturbed, there can be much separation, with the mixing water lying on top. This means that the rest of the mortar becomes stiff. A perfect mortar should not separate significantly.

To determine water separation, take a glass container with an inside diameter of 90 mm and fill it up to 100 mm with mortar, shaking gently. Place the container on a surface where it will not be disturbed and cover to prevent evaporation. After two hours, remove the mixing water that has collected on the top and measure the volume.

The water removed is the same as the water separation and should be at most 7 ml. Alternatively the height of the water layer in the container can be measured. It should be at most 1 mm.

Retention of Mixing Water
In masonry and rendering the mortar must retain the mixing water long enough to allow the masonry unit to be set into place or to allow the render to be smoothed. here is also some surplus water needed to allow the mortar to cure satisfactorily.

The best way to test the ability of the mortar to retain mixing water is to lay test units or to render a sample using the actual masonry units or rendering background. An experienced mason can decide if the water retention of the mortar is acceptable.

Workability
The workability of a mortar is a measure of how easy it is to use the mortar in practice. A number of qualities can be determined in the laboratory, but different craftsmen might have completely different opinions on the workability of the same mortar.

The best way to determine workability is to let experienced masons conduct tests with bricklaying and rendering and to rank the mortars on a scale.

good – acceptable – bad

Initial Adhesion

A mortar should have good contact (wetting) with the background as soon as it is applied. If this does not occur, there is no chance of acceptable adhesion in the long run.

To test the initial adhesion of the units in question, lay a few units together in the traditional way with the joint thickness that will be used. When the joint has set, after at least two minutes, the units are broken apart and the mortared surfaces inspected. If the break occurred in the mortar itself, and there is mortar left on the entire surface of both units, the initial adhesion is acceptable.

For rendering the initial adhesion can be tested in a similar way.

Mortar During Hardening

Shrinkage

Some mortars, especially those with a large proportion of binder or fine aggregate, shrink a lot during curing, which can cause extensive cracking in the finished wall or rendering.

The shrinkage of a mortar can be tested by applying a 15 mm thick layer on a background with very low absorbency. The area should be at least 500 × 500 mm. After curing for a week indoors, inspect the surface for cracking.

If there are no cracks, the tendency toward shrinkage leading to cracks is acceptable.

Hardened Mortar

Strength of the Rendering

Most surface finishes require that the existing rendering has good strength through its entire thickness. Often the surface is hard, while the render farther in is very bad. If such a rendering is treated with a very strong surface finish, the softer layer splits, and the hard surface layer falls off.

To investigate the status of an existing rendering, tap the surface with a little hammer. A ringing sound indicates good strength in the rendering. A dull, flat tone indicates poor strength or poor adhesion between different layers in the rendering. A further test is to press a screwdriver through the render into the background. If the render is hard so that it is necessary to force the screwdriver through, the rendering is acceptable. If it is easy to run the screwdriver in, and if loose fragments fall out, the rendering is too weak for most surface finishes. No surface finish should be applied, but one might paint on a lime paint.

Strength of the Surface to be Finished

All finishing requires a relatively strong surface. A sandy surface always carries the risk of flaking.

The strength of the surface is tested by brushing with a hard brush. A heavy shower of sand, or brush marks in the surface, indicate a surface that is too weak for any treatment.

Masonry Units

Absorbency

The absorbency of the masonry units has a crucial importance for the bricklaying and rendering technique as well as the final result. Using a masonry unit with high absorbency can mean that there is not enough time to adjust the position of the unit before the mortar has set. During rendering, it might not be possible to smooth the surface.

On the other hand a masonry unit with low absorbency can make it difficult to lay more than one or two layers before the units start shifting. Rendering a surface with low absorbency can result in the render sliding off the facade.

The absorbency of masonry units can be classified by the *absorption rate*. This is defined as the increase in weight of a dry masonry unit in partial contact with water for one minute. The bottom surface should not sit more than 3 mm under water, and should be wiped with a damp cloth before weighing. The amount of water absorbed is calculated as kg/m^2.

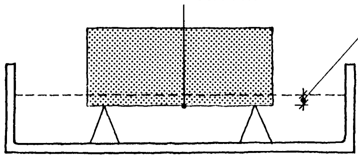

Fig. 12 Determination of Absorbency.

The masonry units are classified as follows.

Absorbency	*Absorption Rate (kg/m^2)*
Very high	> 2.5
High	1.5 – 2.5
Medium	0.8 – 1.5
Low	0.4 – 0.8
Very low	< 0.4

5 Standard Mortars

The table describes some standard mortars according to composition, approximate strength and area of application. All recipes assume that the aggregate is normal sand with a density of 1300 kg/m^3. For other densities, the proportion by weight should be recalculated, see Chapter 2. The strength can vary greatly according to variations in the quality of the binder and aggregate. The values given should be taken as approximations. Strength is also greatly affected by the absorbency of the masonry units. A unit with very low absorbency can result in half the strength, compared to a unit with normal absorbency.

For example:

C = cement, L = lime hydrate, L_h = hydraulic lime,

C 100/300 = 100 kg cement and 300 kg sand,

C 1:3 = 1 litre cement and 3 litre sand,

LC 35/65/400 = 35 kg lime, 65 kg cement and 400 kg sand,

LC 1:1:6 = 1 litre lime, 1 litre cement and 6 litre sand.

Proportion by Weight	*Proportion by Volume*	*Strength (MPa)*	*Use*
C 100/300	C 1:3		Spatterdash coat
C 100/450	C 1:4	12 – 30	Masonry
LC 10/90/350	LC 1:4:15		Spatterdash coat
LC 35/65/400	LC 1:1:6	7 – 15	Spatterdash coat
LC 35/65/550	LC 1:1:8		Masonry, undercoat
LC 50/50/650	LC 2:1:12		Masonry, undercoat
LC 35/65/650	LC 1:1:10		Masonry
L_h 100/750	L_h 1:4	4 – 12	Masonry, undercoat
LL_h 10/90/500	LL_h 1:8:30		Spatterdash coat
LL_h 35/65/500	LL_h 1:2:10		Spatterdash coat
LC 60/40/700	LC 3:1:16		Masonry, undercoat
LC 50/50/950	LC 2:1:18	2 – 8	Masonry, undercoat
L_h 100/900	L_h 1:5		Masonry, undercoat
LL_h 40/60/650	LL_h 2:3:16		Masonry, undercoat
L 100/800	L 1:4	1 – 5	Masonry, undercoat
L 100/1050	L 1:5		Masonry, undercoat

6 Amounts of Mortar Needed

It is not possible to give precise amounts of mortar needed. The joints and their thickness can vary widely. Consumption is also affected by wastage, the evenness of the masonry units, any holes in the units, and in the case of rendering, the evenness of the wall.

The values given below apply to averages for 10 – 12 mm thick joints, "normal" units and normal wastage. If the units are very uneven or have large holes, more mortar is needed. "Wet mortar" means the ready, prepared mix. "Dry mortar" means the dry ingredients before the mixing water is added.

Amounts of Mortar for Masonry

Size of the masonry unit (l × b × h mm)	*Wall thickness (mm)*	*Wet mortar (litre/m^2)*	*Dry mortar (kg/m^2)*
250 × 120 × 65	120	30	50
250 × 120 × 65	250	70	115
200 × 140 × 85	140	30	50
400 × 200 × 165	200	25	40
400 × 300 × 165	300	40	60
700 × 200 × 250	200	20	30
700 × 300 × 250	300	30	45

Amounts of Mortar for Rendering

Coat and Thickness	*Wet mortar (litre/m^2)*	*Dry mortar (kg/m^2)*
Spatterdash coat, 2 mm	2 – 2.5	3 – 4
Undercoat, 10 mm		
even background	12	18
uneven background	12 – 15	18 – 25

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